

**EVOLUTION OF SOLID PROPELLANT
ROCKETS IN INDIA**

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EVOLUTION OF SOLID PROPELLANT ROCKETS IN INDIA

RAJARAM NAGAPPA

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To the fond memory of my parents

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Dr. A.P.J. Abdul Kalam
Former President of India



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FOREWORD

India is self-reliant in Solid Propellant Technology and Rocket Motors. I recall way-back in 1970s with a vision of Dr. Vikram Sarabhai, pioneering efforts came from Dr. V R Gowariker and Mr M R Kurup to develop new compositions for the propellant to be used for SLV-3. Development of four Rocket Motors for SLV-3 simultaneously and testing them at different environment conditions was a real challenge and an effort of first of its kind at that time. Mr. EVS Nambodiri from project side and Mr. Rajaram Nagappa from technology side together put great effort in realising all the rocket motors for SLV-3. Even today the first stage of SLV-3 has become the work-horse booster for PSLV, GSLV and for Agni Missile. Today, India embarked on large Solid Propellant Booster operating in PSLV and GSLV with high strength maraging steel (M250) for the casing and composite nozzle and igniter. It is a great effort from Mr. Rajaram Nagappa who headed the Solid Propellant Rocket Motors Program for PSLV, has consolidated all his experiences in the form of a book **“Evolution of Solid Propellant Rockets in India”**.

In this book Mr. Rajaram Nagappa has brought out sequentially the developments of different Rockets at ISRO and Missiles at DRDO using Solid Propellant technology. I am delighted to go through this book with re-collection of my memories in ISRO days, working with number of colleagues in the evolution of Rocket Motors for SLV-3 and the decision on main Booster for PSLV.

I congratulate Mr Rajaram Nagappa for this valuable edition of the book which will help the budding Engineers, who will be working in the rocket field.

03 August 2013


(A.P.J. Abdul Kalam)

Preface

India has historical record of using rockets as weapons of warfare in the late 18th century. Hyder Ali and later Tipu Sultan maintained a dedicated rocket corps in their army, and in the battle of Pollilur in 1780, Tipu used rockets effectively to rout the British army. After Tipu's defeat by the British in the subsequent Anglo-Mysore war, William Congreve took the captured hardware to England to study the design and modify it. The rockets came to be then onwards known as Congreve rockets; its Tipu and Mysore lineage have been conveniently forgotten. The British established the Cordite Factory at Aruvankadu in Nilgiris, Tamil Nadu in 1904 essentially to make double-base propellant grains for artillery rockets. Modern rocketry in India is just 50 years old and came into being in the early 1960s with the establishment of the Thumba Equatorial Rocket Launching Station, and the associated research and development activities. This initial effort has now grown into a vibrant space programme with the capability to perform end-to-end space missions.

There have been some attempts to write about the historical developments in rocketry and space in India. Narasimha in 1985 wrote about the reemergence of the rocket as a weapon system in the latter half of the 18th century in Mysore. Some aspects of modern day rocketry were described by Dr APJ Abdul Kalam in 1999 in his autobiography, *The Wings of Fire*. A detailed overview of the Country's launch vehicle system development was provided in 2000 by Gopal Raj in his book, *Reach for the Stars—The Evolution of India's Rocket Programme*. Manoranjan Rao and Radhakrishnan have traced the development of rocketry in the Indian Space Research Organisation covering the sounding rockets and launch vehicles in, *A Brief History of Rocketry in ISRO*, which came out in 2012. Manoranjan Rao and Radhakrishnan have devoted a chapter covering the profiles in technology development relating to chemicals and materials. The historical narration relating to missiles is rather sparse. Some aspects of the early days of defence research can be found in *Dare Devil Days* brought out on the occasion of the completion of 25 years of Defence Research and Development Laboratory. A special publication in 2008 similarly described the developments under the Integrated Guided Missile Development Programme. The publication under the title *IGMDP* was published by DRDO to commemorate 25 years of the programme. A similar publication titled, *Glorious Five Decades of HEMRL*, brought out in 2008 to commemorate the Golden Jubilee of the High Energy Materials Research Laboratory traced the history of the laboratory and its major achievements in solid propellants.

Solid propellant rockets have played a key and significant role in the successful evolution of missile and launch vehicle systems in the country. The programmes in both domains went through the phases of experimentation and operationalisation. While new requirement of solid propellant rockets has plateaued out in the space domain, new and diverse requirements continue to be posed for defence systems. Starting from a handful of people in the early 1960s, the solid propellant rocket community in the country can be estimated to be nearly 3000. Starting from one solid propellant plant, the country has more than half a dozen including the ones in the private sector and the Ordnance Factories. Indian industry involvement in the production of input materials, fabrication, and other services is significant.

Literature corresponding to historical narration of such successful systems is sparse. In the field of solid rocket propulsion, the few that are available are technical in nature (HS Mukunda, *Understanding Aerospace Chemical Propulsion*, Interline Publishing, 2004 and Haridwar Singh and Himanshu Shekhar, *Science and Technology of Solid Rocket Propellants*, 2005); and this book is an attempt to provide the background to India's achievements in solid rocketry.

One important fact, which has been emphasised in the text also, is that India has achieved total self-reliance in respect of solid propellant rockets. This happy state of affairs is due to the effort of dedicated and committed persons. Some important stalwarts like WD Patwardhan, MR Kurup, SK Attithan, and K Kishore have passed on leaving indelible marks of their unique contributions. Others are still active and contributing directly or indirectly to the development in this discipline.

I have tried to capture the spirit of self-reliance that pervaded the solid rocket development right from its inception and the high goals it has attained over the years. This is my tribute to one and all who have contributed to this success story.

Bangaluru

Rajaram Nagappa

Acknowledgements

November 2013 will mark the 46th year of the flight of the first indigenously developed rocket RH-75, which was launched from Thumba. In the four and a half decades following this flight, the solid propellant rocket technology has seen tremendous development and crossed important milestones. I felt it was essential to capture some of the historical development and management issues and write them down. The Directorate of Extramural Research and Intellectual Property Rights (ER&IPR), DRDO whom I approached for funding, agreed with the objectives and scope of my proposal and gave me the go ahead. My immense thanks to Dr S Sankaran, the then Director, ER&IPR, and his colleagues in the Directorate for providing the funding, arranging periodic reviews as well as for putting up with the slight delay in the task completion.

In the preparation of this document, I have drawn support and information from former colleagues in ISRO and DRDO scientists – serving and retired – belonging to the solid rocket community. It is only due to their active collaboration that I have been able to complete the task and I offer my sincere and heartfelt thanks to all of them. I wish to particularly mention Shri RN Agarwal, former Director, ASL; Shri Avinash Chander, CC R&D, Strategic Systems; Shri Bikash Bhattacharya, Director HEMRL; Shri PVG Brahmanandam, Scientist, ASL; Shri AK Chakraborti, Director DRDL; Dr Seema Kakade, Scientist, HEMRL; Dr Shrikant Pande, Scientist HEMRL; Shri Pappa Rao, Scientist, ASL; Dr KRK Rao, former Director, HEMRL; Dr VG Sekaran, Director, ASL; and Shri PN Tengli, General Manager, SFC.

Dr A Subhananda Rao, former Director, HEMRL and currently CC R&D has been ever helpful. Discussions with him and the mid-project review taken by him provided very useful inputs in the preparation of this document. I am very thankful to him for hosting me at HEMRL during September–November 2011, which provided me an opportunity to concentrate on preparing the manuscript and to interact with a number of scientists. I am also thankful to Dr Manoj Gupta and his colleagues at SRP who went out of the way to make me feel at home during these two months at HEMRL. The stay at HEMRL provided me an opportunity to interact with Dr Gupta and other scientists. I am thankful to him for this and also for providing me with all the office and library resources and facilitating my visit to sister laboratories.

My own former colleagues in ISRO have been a source of great help. Some have contributed to the write-up, some have dug deep into their memories and provided

me inputs, and others have been helpful in reading and critiquing the write-up. I am deeply indebted to them and particularly to PJ Abraham, AV Hanumantha Rao, K Harinath, Pramod Kale, VN Krishnamurthy, GK Levin, PD Mujumdar, SK Radhamohan, S Ramesh, KS Sastri, V Srinivasan, T Sriram, and K Vishvanathan. I would also like to thank Smt C Sarojini, who helped in transcribing some parts of the manuscript. Shri MC Uttam started his career in solid propellants at RPP, continued with it at SPROB, and has settled down at Pune. He was generous enough to share his long years of experience. I am extremely thankful to him for not only providing inputs on propellant development at ISRO, but also providing me material on the propellant development at DRDO.

Shri T Rajagopal in the SMP Office has been of great help in a variety of ways. He has been as much help to me today as he was when I was in service. It is difficult to put value to the type of friendship and support people like Rajagopal provide – I am deeply indebted to him.

Academic interaction has stood the solid rocket community in good stead. As examples, I have provided glimpse of some interactions. Prof HS Mukunda, former Director, CGPL, IISc; Prof SR Chakravarthy, Aerospace Engineering, IIT-M; and Prof BTN Sridhar, Aerospace Engineering, Anna University readily agreed to my request and provided inputs on the research relating to solid propellants undertaken in their institutions. I am thankful to them for their contribution, which I have included in the text with very minor editing.

Industry in India has played a positive role in the development of capability and building of capacity in solid rocket systems. Some industrial contributions are highlighted in the document based on inputs provided by the Company Executives. I am thankful to Shri VM Parthasarathy of Walchandnagar Industries Ltd, Shri AM Palanisamy of Aerospace Materials Ltd, Shri Peter Valeth of Valeth High Tech Composites, and Shri AN Gupta of Premier Explosives Ltd for sparing the time not only for discussion but also for arranging visits to their facilities.

Shri SK Jindal , Director, DESIDOC and his dedicated colleagues have gone out of the way to make this publication happen. Ms Anitha Sarvanan is a perfectionist and has ensured the quality of the figures by getting many of them redrawn and asking me to provide better quality pictures. Her scrutiny and editing of the text as well as getting the document reviewed has helped me to correct and sharpen the text. She and her colleagues in DESIDOC deserve. I am happy to record their contribution in bringing the book to final shape.

My wife Malathi in her own quiet fashion has been a great motivator. She has put up with my odd hours of work on the manuscript without complaining and has kept me company when I have preferred to work out of Bangaluru. She has been a useful sounding board for ideas and has provided insightful comments. I owe a lot to her in the completion of this task.

Rajaram Nagappa

List of Acronyms

ABM	apogee boost motor
ACP	advance casting powder
ADE	Aeronautical Development Establishment
ADN	ammonium dinitramide
AMPL	Aerospace Materials Private Ltd
AP	ammonium perchlorate
APEP	ammonium perchlorate experiment plant
ARCAS	Atlantic Research Corp
ARCO	American Richfield Co
ARDB	Aeronautics Research and Development Board
ARDE	Armament Research and Development Establishment
ASL	Advanced Systems Laboratory
ASLV	Augmented Satellite Launch Vehicle
ASP	Alloy Steel Plant
ATM	anti-tank missile
BAMO	bis azide methyl oxetane
BARC	Bhabha Atomic Research Centre
BEM	ballistic evaluation motor
BHEL	Bharath Heavy Electricals Ltd
BKNO ₃	boron-potassium nitrate
BSF	Border Security Force
CECRI	Central Electrochemical Research Institute
CFA	Cordite Factory Aruvankadu
CFD	computational fluid dynamics
CFRP	carbon fibre reinforced plastics
CGD	Control and Guidance Division
CNES	Centre National d'etude Spatiales
CTPB	carboxy terminated polybutadiene
CWS	central workshop
DAE	Department of Atomic Energy
DFVLR	Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt
DMRL	Defence Metallurgical Research Laboratory
DoS	Department of Space

DOVAP	doppler velocity and position
DRDL	Defence Research and Development Laboratory
DRDO	Defence Research and Development Organisation
DTA-TGA	Differential thermal analysis–thermogravimetric analysis
EDB	extruded double-base
EPDM	ethylene propylene diene monomer
ERDL	Explosives Research and Development Laboratory
ESR	electro-slag refined
FEM	fluid energy mill
FRPD	Fibre Reinforced Plastics Division
GAP	glycidyl azide polymer
GFRP	glass fibre reinforced plastics
GoCo	Government owned–contractor operated
GSLV	Geo-synchronous Launch Vehicle
GTO	geostationary transfer orbit
HEMRL	High Energy Materials Research Laboratory
HNF	hydrazinium nitroformate
HPM	high performance motor
HTPB	hydroxy terminated polybutadiene
IAF	Indian Air Force
ICBM	inter continental ballistic missile
IGMDP	Integrated Guided Missile Development Programme
IGY	International Geophysical Year
ILSS	inter laminar shear stress
INCOSPAR	Indian National Committee for Space Research
INDAL	Indian Aluminum Company
IPP	ISRO polyol propellant
ISAS	Institute of Space and Astronautical Science
ISRO	Indian Space Research Organisation
ITE	integral throat and entrance
IUS	inertial upper stage
JATP	Joint Advanced Technology Programme
JPL	Jet Propulsion Laboratory
L&T	Larsen & Toubro Ltd
LiF	lithium fluoride
LVDT	linear variable differential transformers
MAPO	methyl aziridinyl phosphine oxide
MEOP	maximum expected operating pressure
MIDHANI	Mishra Dhatu Nigam
MIT	Madras Institute of Technology
MSIP	Maraging Steel Indigenisation Programme

NAL	National Aerospace Laboratory
NASA	National Aeronautics and Space Administration
NC	nitrocellulose
NDE	non-destructive evaluation
NDT	Non-destructive testing
NG	nitroglycerine
NIMMO	nitromethyl methy oxetane
NOCIL	National Organic Chemical Industries Ltd
OFI	Ordnance Factory, Itarsi
PBAA	polybutadiene acrylic acid
PBAN	polybutadiene acrylic acid acrylonitrile
PED	Propellant Engineering Division
PEL	Premier Explosives Ltd
PFC	Propellant Fuel Complex
PGN	polyglycidyl nitrate
PPG2000	polypropylene glycol
PRL	Physical Research Laboratory
PSLV	Polar Satellite Launch Vehicle
PSND	Propulsion Engineering Division
PTA	pilot-less target aircraft
PU	polyurethane
PVC	poly-vinyl chloride
R&ML	Rockets and Missiles Laboratory
RAP	Resins and Allied Products
RATO	rocket-assisted take off
RFF	Rocket Fabrication Facility
RPE	Royal Propulsion Establishment
RPP	Rocket Propellant Plant
RSRM	reusable solid rocket motor
RTH	Rocket Test House
SA to RM	Scientific Advisor to Raksha Mantri
SCP	slurry casting powder
SEM	Scanning electron microscope
SEP	Société Européene de Propulsion
SFC	Solid Fuel Complex
SITVC	secondary injection thrust vector control
SLV	satellite launch vehicle
SNPE	Société Nationale Poudres et Explosifs
SPAN	SPROB Augmentation Project
SPROB	Solid Propellant Space Booster Plant
SPSB	Solid Propellant Strand Burner

SRMU	solid rocket motor upgrade
SSPO	sun-synchronous polar orbit
SSTC	Space Science and Technology Centre
STEX	Static Test and Evaluation Complex
STRD	Structural Engineering Division
SWDT	Special Weapons Development Team
TDI	toluene di-isocyanate
TERLS	Thumba Equatorial Rocket Launching Station
TMP	trimethylol propane
TSLA	titanium substrate lead dioxide anodes
VSSC	Vikram Sarabhai Space Centre
WIL	Walchandnagar Industries Ltd
WIMCO	Western India Match Company

Introduction

The Cordite Factory Aruvankadu (CFA), in Nilgiris district of Tamil Nadu has been producing double-base propellants for artillery rockets for more than 100 years now. Modern rocket technology as we know it, had its beginning in the 1960s, went through the development phase in the decades of 1970, 1980, and 1990, and has been operationalised since then. The Indian Space Research Organisation (ISRO) and the Defence Research and Development Organisation (DRDO) are the two entities involved in the development of rocket technology and realisation of rocket systems. The propulsion system powers the rocket or missile to meet its functional requirement and hence is one of the principal subsystems. Chemical rocket propulsion systems use either solid propellants or liquid propellants, and of these, the solid propellant rockets are the preferred choice for boosting space launch vehicles and for most missile applications.

Rocket development in the civilian sphere had its roots in the study of the ionosphere and for gathering monsoon related data over the equatorial region. Sounding rocket flights were taken up from the Thumba Equatorial Rocket Launching Station (TERLS) (now part of the ISRO) in 1963, and technology acquisition from abroad as well as technology development was taken up shortly thereafter. Dr Vikram A Sarabhai, the founding father of the Indian Space Programme laid great stress on self-reliance and demanded that rocket development activity should develop on our own steam beyond the initial technology acquisition for sounding rockets. In hindsight, this dictum was remarkable as at that time it was possible to negotiate and procure advanced technology like that of the Delta Launch Vehicle without significant difficulty. The young band of engineers recruited by Dr Sarabhai went about the technology development tasks with enthusiasm, and over the years reached high levels of proficiency and expertise. Managerially, ISRO enjoyed one great advantage of being able to set the product specifications realistically in relation to the development needs and requirements as it foresaw. Quite often these specifications were conservative and did not represent the top of the line achievements in the West. In case of technology issues cropping up during the development, performance compromises could be conditionally accepted and were never reasons for outright rejection. To be fair, most technology developments in general either met or exceeded the target specifications.

Missile research and development took birth in the early 1950s with the formation of the Defence Science Organisation (predecessor to the present DRDO) under the leadership of Dr DS Kothari, who was the first Scientific Adviser to the Defence Minister. From its inception, the organisation was closely linked to the three services.

In 1958, a Guided Missile Study Team, later known as the Special Weapon Development Team was formed with the objective of studying the requirements of guided missile design and development. Initial efforts included the feasibility study of first generation anti-tank missile system and a high-altitude sounding rocket. Attempts at indigenising procured rocket systems were also on the anvil. However, these efforts did not translate into tangible development and operational systems. It was the initiation of the Integrated Guided Missile Development Programme (IGMDP) in 1983 that saw major developmental activities fructify into operational systems. Dr VS Arunachalam, the then Scientific Adviser to the Raksha Mantri and Dr APJ Abdul Kalam who was the Director of the Defence Research and Development Laboratory (DRDL) piloted the IGMDP in its formative years.

Unlike the case of ISRO, the development targets for DRDO were drawn up to meet the customer requirements. The three wings of the defence services, as customers were alive to: (a) the country's requirements from defence considerations as well as the weapon type holdings of the adversary countries, and (b) the top level armament available from the international market for a specific role. Added to this was the diverse range of application dictated requirements. Consequently, the technology development for DRDO was much more challenging as they had to compete with procurable stores from abroad in meeting demanding specification needs within limited time frames. The safety and reliability challenges were also of a higher order as many of the systems had to operate from manned platforms like aircraft, ship or submarine. Development and deployment of systems developed by ISRO had to perform from either the sounding rocket launching station at Thiruvananthapuram or the satellite launch station at Sriharikota. The climatic variations were quite narrow and the storage periods for the systems were also quite small of the order of five years. The defence systems on the contrary had to perform over long storage times under extremes of environment conditions prevailing in coastal, desert, and Himalyan regions of the country. Service requirements of low or zero exhaust smoke visibility in some tactical systems, missile canisterisation, and mobility requirements posed problems of a different order in terms of system design robustness and ruggedness without compromising the overall performance.

In the author's opinion for the development of strategic systems, the successful flight of SLV-3 in July 1980 proved to be the game changer as it opened up the possibility of designing and developing long range missile systems using similar technologies. India had already carried out the peaceful nuclear explosion in May 1974. Its eventual conversion into a weapon system had merit only if it could be dovetailed with appropriate delivery systems. It was evident to the Indian defence specialists that in addition to aircrafts, missiles were essential as delivery systems with long standoff capability. The defence specialists also realised that this will have to be an indigenous effort and it would be futile to even consider the possibility of procuring long-range missiles from abroad. Hence, the development of Agni missile as a technology demonstrator became an essential component of the IGMDP. Subsequent events have proved the wisdom of this approach. The Missile Technology Control Regime (MTCR) came into being in 1987, and it became impossible to procure missiles with capability to launch payloads of 500 kg to range of 300 km. The constraints of the control regimes also put spokes in technology cooperation and technology flow between the civilian and defence wings, thus precluding the developments in the defence sector to benefit from

the higher level of technology achievements of ISRO prevailing in the 1980s. It must however, be borne in mind, that no restrictive regime can totally insulate the transfer of knowledge and expertise within the country. In a country like India, there are a number of professional forums organising conferences and seminars on engineering topics, which provide opportunity for specialists to discuss and exchange ideas. Also, there is mobility of people between organisations both in the government and the private sector, and the expertise also moves. The Indian industry serves as a platform common to all users needing expert services and also serves as a base for exchanging good practices in fabrication, processes, inspection, and quality control.

In this new scenario, the development targets of strategic missile systems like Prithvi and the Agni series were pegged realistically initially based on the technology capability and critical material availability (akin to the case of civilian space systems), but gradually progressing to incorporation of modifications, improvements and innovation. While this situation may have resulted in some level of *de novo* learning in DRDO and delays in development, it helped in creating another cadre of specialists in design and development; in creating processing and manufacturing capacity; in creating test facilities; and in creating additional industrial support bases. The solid propellant rocket systems developed in both ISRO and DRDO have reached a level of maturity, and are comparable in characteristics and performance to similar systems in the world.

It is important to acknowledge the leaders who steered the programmes in their formative years and directed the development pathways. Undoubtedly in the space arena, Dr Homi Bhabha, Dr Vikram Sarabhai, Satish Dhawan, and Brahm Prakash hold a special and uncontested space. An excellent biographical sketch of these stalwarts is provided by PV Manoranjan Rao and P Radhakrishnan in their book 'A Brief History of Rocketry in India' by Universities Press (India) Private Ltd in 2012. The author while reviewing this book for Current Science* had commented: 'Bhabha, Sarabhai, Dhawan, and Brahm Prakash stewarded the space programme with conviction and nobility of leadership – qualities which emboldened the ISRO community to delve into uncharted territory with confidence. The leadership was open to the fact, that while mastering technology mistakes will occur and the solution lay in understanding the issues, analysing them in depth and correcting them. These leaders were not risk averse, but could take decision based on reasoned thinking. In turn they groomed good leaders'. Among the personalities groomed by these leaders included APJ Abdul Kalam, VR Gowariker, MR Kurup, and AE Muthunayagam who played key roles in technology development, facility establishment, and putting solid rocket technology on a firm footing. Major technology achievements of state-of-the-art large solid propulsion systems needed for the Polar Satellite Launch Vehicle (PSLV) happened during the chairmanship of UR Rao. Subsequent chairmen have also leant their weight and support in sustaining and nurturing the solid propellant rocket requirements.

In DRDO also, the leadership provided by successive Scientific Advisors and Directors of DRDL and High Energy Materials Research Laboratory (HEMRL), then known as Explosives Research and Development Laboratory helped in the development and realisation process of various tactical and strategic missiles. Dr BD Nag Chaudhari initiated studies on the design of multi-stage vehicle systems;

*Nagappa, R. & Rammurthy, Y.N. Book Reviews. *Current Science*, 2012, **103**(8), 946–47.

Prof MGK Menon in 1975, set up the Missile Policy Committee for studying the requirements of the services for different categories of missile systems; and in April 1982, Dr VS Arunachalam formed a missile study team to work out missile system requirements to meet short term and long term threat profiles. The Missile Study Team was chaired by Dr Kalam and their recommendations manifested as the Integrated Guided Missile Development Programme. Earlier directors of DRDL – Air Commodore V Ganesan, Air Commodore VS Narayanan, and SL Bansal contributed to the establishment of the laboratory facilities and infrastructure. It was under Dr Kalam that full-fledged missile development activity took shape at DRDL starting from 1982. The key people behind the missile development activity based on solid propellants in the formative years included RN Agarwal, NR Iyer, SR Mohan, Prahlada, and VJ Sundaram, WD Patwardhan, KRK Rao, and Haridwar Singh. They provided the early leadership in the development of solid propellants and propellant facilities.

The separate and independent development of solid propellant rocket and missile systems in ISRO and DRDO has essentially resulted in positive fallouts. One such fallout is the creation of capacity and capability in both institutions, and the other is creation of a diverse industrial base relating to input materials, fabrication, and processes.

Chapter 1

The Beginning

The rockets as weapons of war have been around for a long time. The Chinese are credited with their invention and use as fire arrows in their war against the Mongol hordes in the year 1232. The Europeans used them in the 14th and 15th century. Rockets are not mentioned in the history books thereafter till Hyder Ali and his son Tipu Sultan made improvements in the design and used it with telling effects on the British Army in the famous battle of Pollilur in 1780 and also in the later Anglo-Mysore wars. Their rockets used steel casing of 60 mm diameter and 200 mm length, which were filled with gun powder. The steel casing allowed combustion at high pressure resulting in higher thrust and higher range. A sword attached to the fore-end of the rocket acted as a bayonet as well as stabilised the missile in flight. Infact, the Mysore Army under Haider Ali and then Tipu Sultan had a dedicated rocket corps. The British were greatly impressed by Tipu's rockets and shipped back the spent rocket casings to England for study and analysis. Colonel (later Sir) William Congreve was mainly responsible for the improvements in the Mysore rockets. Consequently, the rockets came to be known as Congreve Rockets.

Rockets in one form or the other figured in subsequent years as war weapons, till improvements in artillery eclipsed them around the middle of the 9th century. Rocketry re-emerged in early 20th century, but on more scientific lines, with experimentation and exploration as the main drivers. Konstantin Tsiolkovsky in Russia published his work entitled 'The Exploration of Cosmic Space by Means of Reaction Devices' in 1903. Twenty years later, Hermann Oberth brought out his thesis 'By Rocket into Planetary Space'. Experimental rocketry was undertaken by Robert Goddard and he successfully flew his liquid rocket in March 1926. Advances in rocketry came about rapidly thereafter with the German V-2 making its presence felt emphatically in World War II. The V-2 rocket technology and some of the scientists involved in its development provided the nucleus for the post-war rocket and missile efforts in both Russia (then Soviet Union) and the USA. The launch of Sputnik on 04 October 1957 heralded the modern space age, and the last 50 years have seen an explosive growth in the exploration and utilisation of space for a variety of applications.

In India, artillery rockets have been around for a long time. The Cordite Factory at Aruvankadu in Tamil Nadu established in January 1904 has been producing cordite propellants for artillery and gun rockets.

The High Energy Materials Research Laboratory (HEMRL), Pune is the premier laboratory of the Defence Research and Development Organisation (DRDO), specialising in the R&D of solid propellants. This laboratory has a history of over a 100 years – it started functioning as the Chemical Examiner's Office in Nainital in 1908. The laboratory moved to Pune in 1936 and continued to function as Chemical Inspectorate and later as the Chief Inspectorate of Military Explosives. It was rechristened as the Explosives Research and Development Laboratory (ERDL) in 1960 and tasked with the R&D of high energy materials.

Dr Vikram A Sarabhai, the founder of the Indian Space Programme was by training a cosmic ray physicist. His research interest in cosmic ray physics led him to establish the Physical Research Laboratory (PRL) in November 1947. The laboratory initially functioned from Sarabhai's home before moving into the premises of the Mahatma Gandhi Science College. The laboratory had on its rolls eminent physicists like Prof KR Ramanathan, Prof PR Pisharoty and students who played an active role in the development of the country's space programme in later years. PRL was an active participant in the International Geophysical Year (IGY) during 1957–58 and contributed to research related to ionospheric studies, cosmic rays, geomagnetism, and meteorology. Dr Sarabhai was keenly interested in the observational studies of the impact of solar activity on cosmic rays and the IGY studies helped him to look at the potential of space for furthering research and other spin-offs. The Indian National Committee for Space Research (INCOSPAR) was constituted in 1962 under the Tata Institute of Fundamental Research and was the nucleus for the growth of civil space programme of the country. The initial impetus was the growing interest in upper atmosphere physics in the West and both Dr Homi Bhabha and Dr Vikram Sarabhai were quick to see the opportunities rockets provided for such studies. Bhabha and Sarabhai selected Thumba, a fishing village near Thiruvananthapuram for locating India's sounding rocket preparation and launch station. All the preparatory work was simultaneously undertaken, and on 21 November 1963, a US supplied Nike-Apache rocket carrying sodium vapour payload was launched from Thumba, heralding India's entry into space. India's space programme, starting with an initial modest beginning of designing experiments and building payloads to be flown on procured rockets from abroad, has over the years, evolved into an all-round capability involving launch vehicles, application, and scientific satellites.

The foundation for Indian Space Research Organisation's (ISRO's) space programmes started with solid propellant rockets. Initial applications were for the Sounding Rocket Programme, graduating to satellite launch vehicles. India's first two satellite launch vehicles, the SLV-3 and the Augmented Satellite Launch Vehicle (ASLV) used solid propellants for the main stage propulsion, with pressure-fed liquid engines providing the steering controls for the second and third stages. The Polar Satellite Launch Vehicle (PSLV) uses two solid stages which compare very favourably with international solid rocket motors of the same class. The S-139 booster of PSLV boosts the Geo-synchronous Launch Vehicle (GSLV) also.

The Defence Research and Development Laboratory (DRDL) at Hyderabad and HEMRL, Pune are the two main laboratories of DRDO involved with the development of propulsion systems and solid propellants, respectively.

The Beginning

The solid propellant rocket development work in DRDO laboratories started with end applications in mind. A Special Weapons Development Team (SWDT) had been formed in 1958–59 in the Defence Science Organisation at Delhi. The SWDT was tasked with studying the requirements of Guided Missile Design and Development in the country. Besides planning for the establishment of the research, design and development infrastructure, the team proposed two project studies. One project study was towards the development of a first generation anti-tank missile (ATM). The main aim of the feasibility study was to get hands-on experience in understanding the technological issues in the realisation of such a missile system. The second study was to explore the evolution of high altitude sounding rockets, based on rockets and supporting equipment available with the Armed Forces. The second project on sounding rockets did not continue, but the development of ATM was pursued with full vigour.

Over the years, the laboratories of the missile complex have successfully brought out many tactical and strategic missiles, and in many cases, passed on the technology to Ordnance Factories and industry for production. Major development efforts intensified after the enunciation of the Integrated Guided Missile Development Programme (IGMDP) in July 1983. This programme involved development of both strategic and tactical missiles employing solid, liquid, and ramjet propulsion systems. Subsequent to IGMDP, DRDO has realised more powerful systems to power the variants of the Agni missile. DRDO has also worked on solid rocket systems for submarine launch applications as well as for air defence requirements. The overall system requirements of the missiles required additional layers of planning over their space counterparts. Demanding user specifications, production setup, technology transfer for production, field deployment requirements, environmental conditions, integration with different launch platforms, and training the ultimate users posed many challenges; and it is indeed creditworthy that DRDO has met these challenges very successfully.

The solid rocket/missile development in both ISRO and DRDO has followed independent paths with some similarities. In the process, specialist knowledge in many disciplines, large scale facilities, inspection, quality control, test procedures, and test facilities have been established. In both the establishments, the development cycle involved a few failures, which have provided important lessons for system correction and design improvements. A large industrial support base has also been established. New systems are being developed in both establishments – while ISRO is working on larger systems for its GSLV Mk III launch vehicle, DRDO programmes encompass newer applications.

The journey from the early days to the present capability is captured in the ensuing chapters.